Argonne National Laboratory
HEP Theory Group

Summary of Research Activities

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Composition of the Group

- Theory Group has six permanent staff members:

  E. Berger (Collider physics, QCD, BSM)
  G. Bodwin (QCD, Quarkonium physics)
  D. Sinclair (Lattice gauge Theories)
  T. Tait (Collider physics, BSM, Cosmology)
  C. Zachos (Mathematical Physics)
  C. Wagner (Collider Physics, BSM, Cosmology)

- Tim was recently hired. He is an expert on collider, Higgs, top-quark and beyond the Standard Model physics.

Productivity

- Group has been very productive on a broad range of areas of physics.

  In the last five years, staff members have published 100 articles in refereed journals. This includes many articles published with more than one staff member as a co-author. Independent postdoc articles also quite significant in number (more than 50 articles).

- Theory group is very strong in the areas related to phenomenology of particle physics: Collider physics, QCD, Higgs physics, heavy quarkonia and beyond the standard model phenomenology.

- The group has produced many relevant articles in the areas of cosmology and astroparticle physics, in particular on the questions of

  dark-matter and baryogenesis.

- The group is also strong in non-perturbative studies of QCD, as well as the analysis of other non-perturbative configurations, like Skyrmions and instantons in four and five dimensions.

Postdocs

- Activities of the group have been reinforced by several young postdoctoral fellows.
- Most of them have found excellent positions and carry successful careers after their stay at Argonne
- Notable cases are John Campbell, Cheng-Wei Chiang, David Kaplan, Jing Jiang, Jungil Lee, Geraldine Servant, Irina Mocioiu and Tim Tait.
- Excellent group of postdocs joined us in last years: C. Balazs (collider physics, BSM, dark matter), P. Batra (collider physics,BSM), B. Lillie (collider physics, BSM) and P. Nadolsky (QCD, collider physics).

Contact with the University of Chicago

- One of the staff members, C.W., has a joint position with the University of Chicago and is teaching a course per year. He is now appointed as a full professor there, holding a tenured, half-time position.

- Two students from the UofC, D. Morrissey (last year) and A. Menon, have been working regularly at the Theory Group, and a few more are joining the group. Morrissey moved in October to the Univ. of Michigan, Ann Arbor

- Successful Argonne/UofC joint postdoctoral program, mantained for the last four years. All the postdoctoral fellows participating in this program obtained professorships in different Universities around the world, soon after leaving Argonne (Kaplan), or during their stay at the laboratory (Chiang, Servant).

- Recent postdoc (Mocioiu) got a tenure-track position at Penn State. We just hired B. Lillie, a Stanford student, to fill-out the joint postdoctoral position.

Organization of Workshops and Schools

- The group has organized seven international workshops at the Argonne HEP Division in the last five years.

- Subjects included
- Higgs, Supersymmetry, extra dimensions (E. Berger, T. Tait and C. Wagner)
- Neutrino Physics (E. Berger, M. Goodman, C. Wagner)
- QCD in extreme environments (D.K. Sinclair)
- Brane Dynamics (C. Zachos)

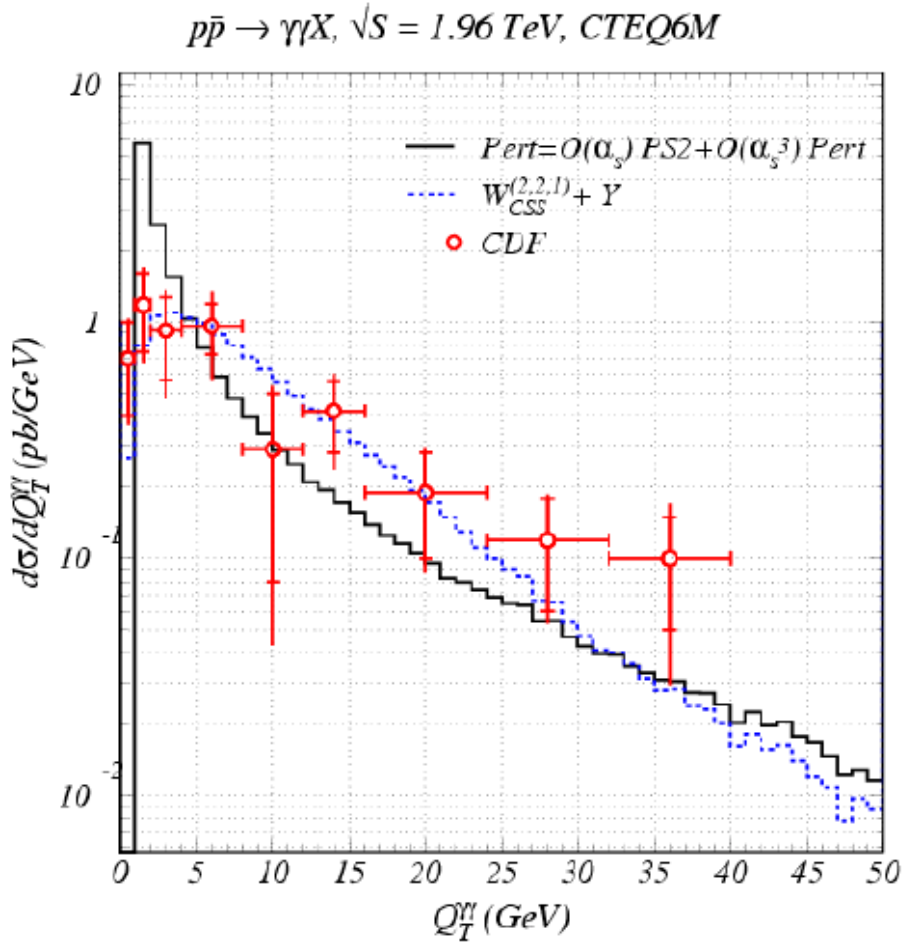
It has also host two Greater Chicagoland Meetings and Lab-wide Theory Meetings.

All these activities have greatly increased the visibility of the group.

Theory Group Research Highlights

QCD Analyses

Diphoton production at hadron colliders



Balázs, Berger, Nadolsky, Yuan 2005

Diphoton production is the most important background for light (SM like) Higgs searches at hadron colliders

QCD corrections are large, especially at small $Q_T^{\gamma\gamma}$, due to multiple soft gluon radiation

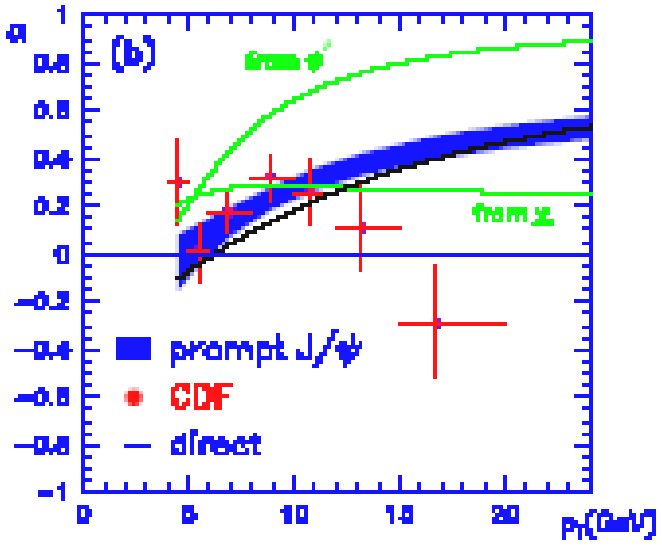
The new resummed prediction, that includes the $q\bar{q}$, $\overset{(-)}{q}g$, $gg \to \gamma\gamma X$ processes at NNLL, provides an excellent description of the CDF Run II data

Lattice Computation of Spin Correlations in NRQCD Color-Octet Matrix Elements

G. Bodwin, J. Lee, D. Sinclair

(hep-lat/0503032)

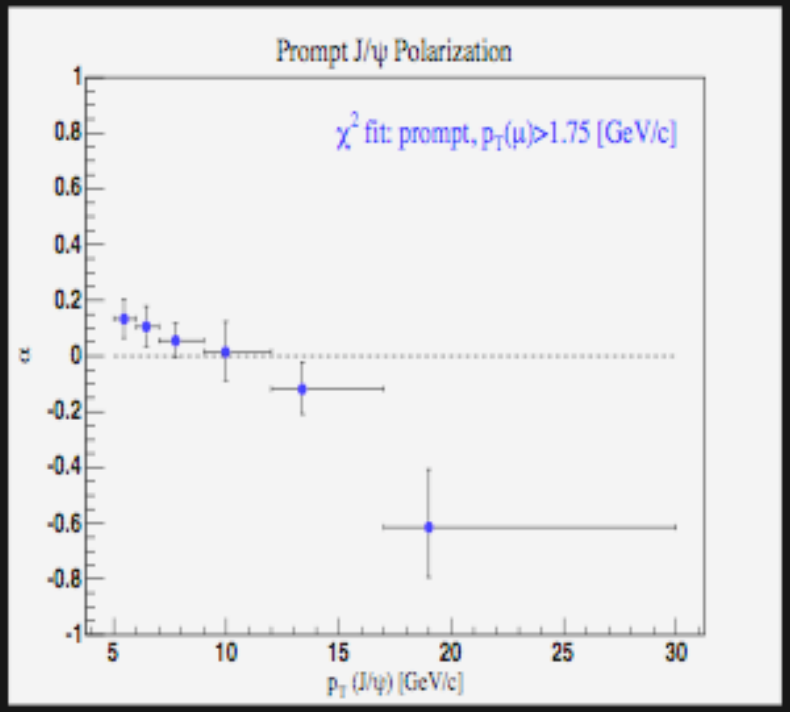
- NRQCD factorization predicts that J/ψ's produced at large p_T at the Tevatron have a large transverse polarization (P. Cho, M. Wise).
- The CDF data do not support this prediction:

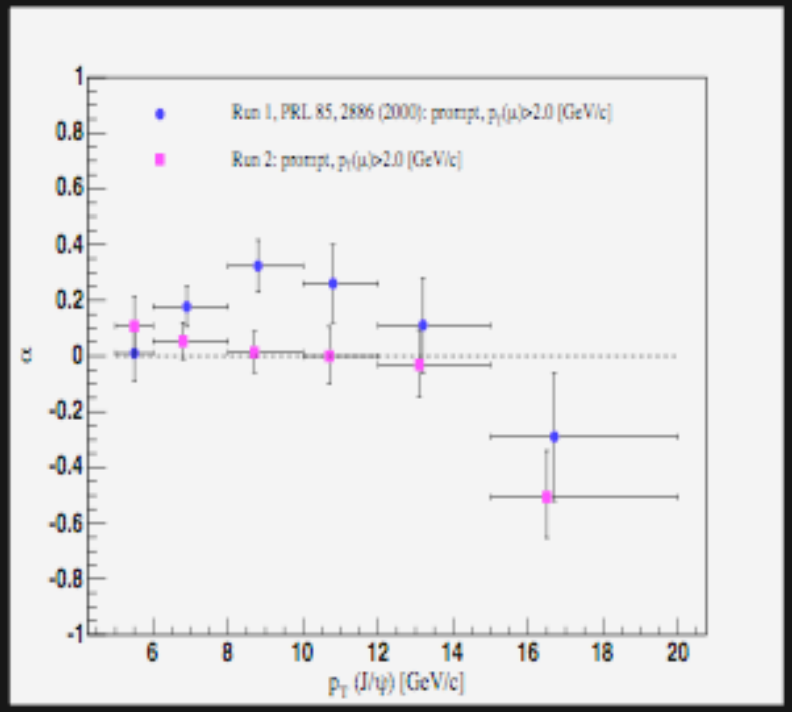


$\alpha = 1$ is 100% transverse polarization; $\alpha = -1$ is 100% longitudinal polarization.

- It has been suggested that, contrary to the NRQCD velocity-scaling rules, de-polarizing spin-flip processes dominate J/ψ production at large p_T.

Updated Result





Charmonium Matrix Elements

(normalized to the leading color-singlet M.E.)

spin transition	hybrid	nrqcd	v scaling
singlet $\longrightarrow$ triplet	$6.397(8) \times 10^{-2}$	$2.90(3) \times 10^{-3}$	$v^3/(2N_c) \approx 2.7 \times 10^{-2}$
triplet $\longrightarrow$ singlet	$2.938(7) \times 10^{-2}$	$1.13(2) \times 10^{-3}$	$v^3/(2N_c) \approx 2.7 \times 10^{-2}$
singlet $\longrightarrow$ singlet	$5.03(9) \times 10^{-4}$	$9.7(2) \times 10^{-4}$	$v^4/(2N_c) \approx 1.5 \times 10^{-2}$
triplet $\longrightarrow$ triplet	$1.57(2) \times 10^{-3}$	$1.016(8) \times 10^{-3}$	$v^4/(2N_c) \approx 1.5 \times 10^{-2}$
up $\longrightarrow$ up	$4.57(6) \times 10^{-4}$	$1.019(8) \times 10^{-3}$	$v^4/(2N_c) \approx 1.5 \times 10^{-2}$
long. $\longrightarrow$ transverse	$2.82(4) \times 10^{-4}$	$2.8(7) \times 10^{-6}$	$v^6/(2N_c) \approx 4.5 \times 10^{-3}$
down $\longrightarrow$ up	$8.48(5) \times 10^{-4}$	$1.4(2) \times 10^{-6}$	$v^6/(2N_c) \approx 4.5 \times 10^{-3}$

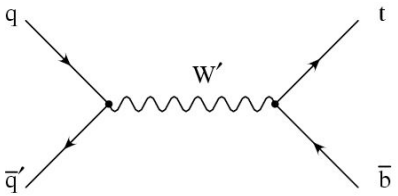
- Heavy-quark Green's functions were computed with "hybrid," "nrqcd," and "coulomb" actions. Focus on the "nrqcd" action—controls power contributions.
- v-scaling estimates are too large for the higher-order matrix elements, but the hierarchy of v-scaling (the v-expansion) is correct.
- The triplet $\longrightarrow$ singlet transition rate is comparable to the triplet $\longrightarrow$ triplet transition rate.
  - η_c production rate at the Tevatron may be comparable to the J/ψ production rate.
- The longitudinal $\longrightarrow$ transverse transition rate is small compared with the transverse up $\longrightarrow$ transverse up transition rate.
  - The prediction of large transverse polarization at large p_T at the Tevatron is supported.

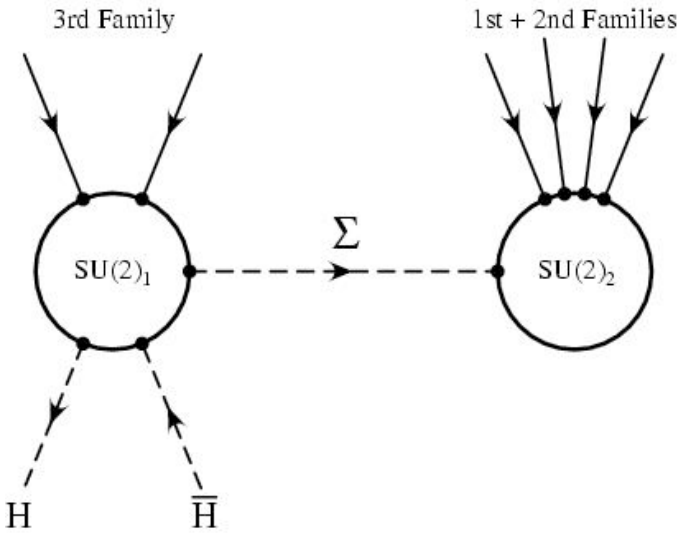
Higgs and Beyond the Standard Model Physics

An SU(2) Gauge Extension

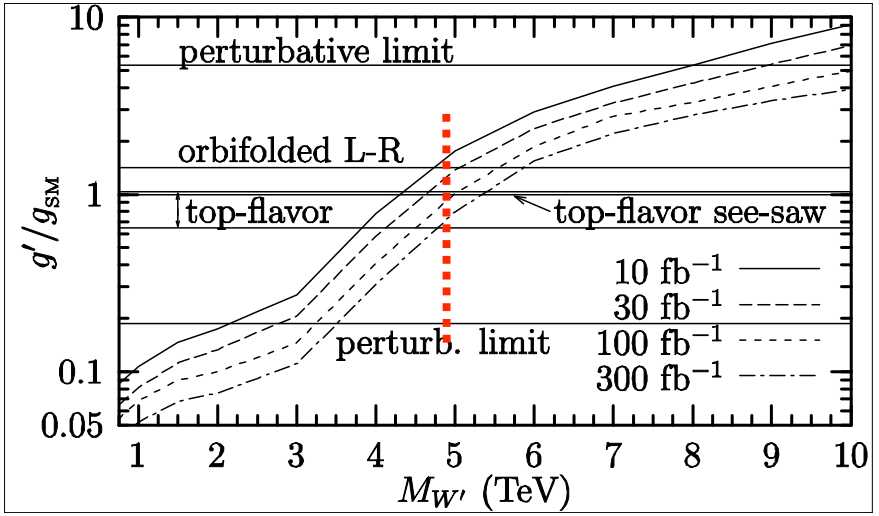
P Batra, A. Delgado, D.E. Kaplan, T Tait, JHEP 0402,043 (2004)

- Solution to little hierarchy problem:
  Increase the Higgs mass by having it participate in new strong gauge interactions.
- Consistent with data, m_H may increase as high as **250 GeV** – radically affecting MSSM Higgs phenomenology.
- We invoke a new SU(2) interaction under which the Higgses and third family are charged.
  $SU(2)_1 \times SU(2)_2 \times U(1)_Y$
- This model has been called "**Topflavor**": a separate weak interaction for the 3rd family.
- Because $SU(2)_1$ is asymptotically free, it has no problems with strong coupling at high energies.
- The extra W's are a hallmark of the model, and can be observed in single top at the LHC.



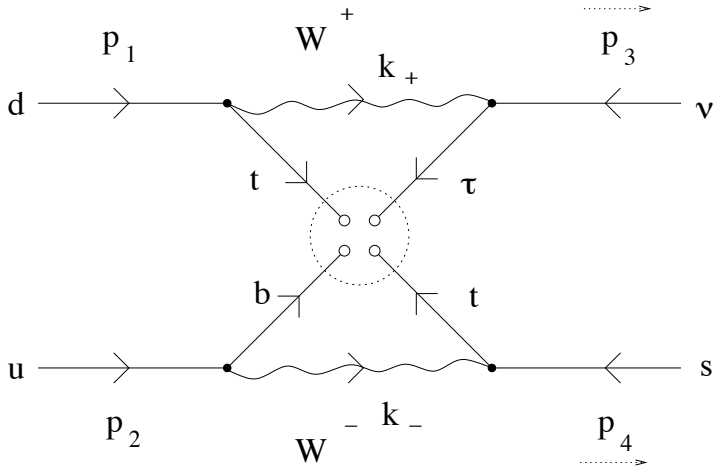


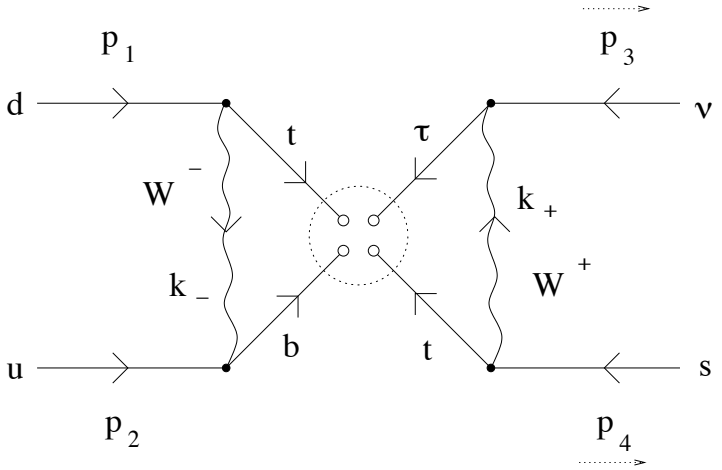
Z. Sullivan, hep-ph/0306266



Proton Decay

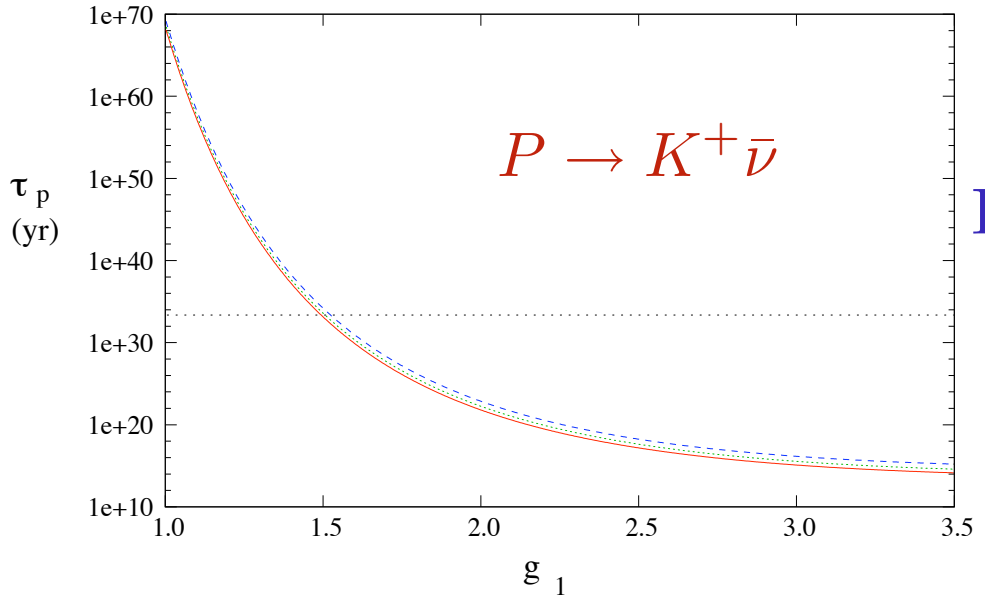
- In the absence of additional fermion degrees of freedom, proton must decay into leptons.
- Hence, proton decay requires B and L violation. Both quantum numbers are violated by anomalous processes, which, however, are exponentially suppressed $\Gamma \simeq \exp(-4\pi/\alpha_W)$
- In addition, in the SM, B and L are violated by at least three units, making proton decay impossible. Both restrictions are avoided in the above theory.





Constraints on the strong coupling

D. Morrissey, T. Tait and C.W. PRD 72, 095003, 2005



$$\Gamma \simeq \frac{m_P^5}{u^4} \exp(-4\pi/\alpha_1)$$

Figure 4: Proton lifetime due to $SU(2)_1$ instantons for $u = 2$ TeV (solid red), $u = 3$ TeV (dotted green), and $u = 5$ TeV (dashed blue). Also shown in this figure (flat dotted line) is the 90% c.l. experimental lower bound on the proton lifetime [30].

Higgs Boson Plus 2 Jets: WBF Signal at NLO and QCD Backgrounds

E. L. Berger and J. Campbell

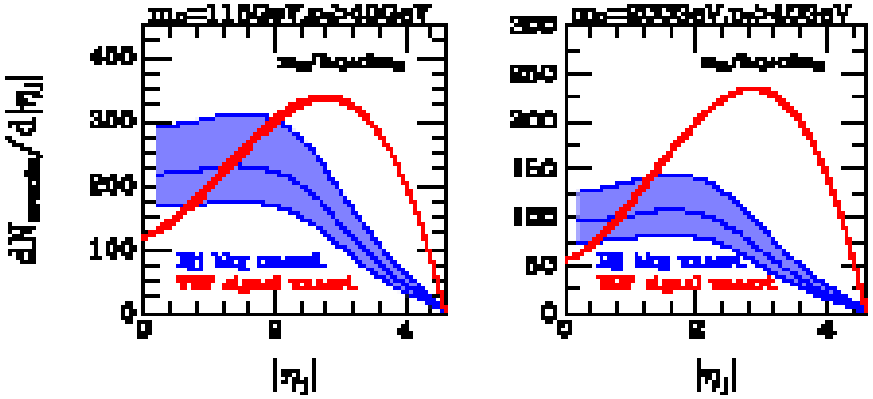
Phys. Rev. D70, 073011 (2004) and hep-ph/0408259

- Motivation: after discovery of the Higgs boson, the goal becomes the measurement of its couplings. How well can this job be done in the weak boson fusion (WBF) sample?
- Full QCD calculation of $H + 2$ jet processes

– to gauge the effectiveness of cuts used to select the WBF signal, and

– to evaluate the accuracy with which couplings g_H can be determined in experiments at the CERN LHC

- The WBF signal and the QCD $H + 2$ jet backgrounds, along with estimated uncertainties, as a function of the rapidity of a tagging jet:



- Estimate $\delta g_H / g_H \sim 10\%$ at LHC after 200 fb^{-1}. At a 500 GeV ILC, the expected accuracies are 3% in g_{HZZ} and 3% to 7% in g_{HWW} after 500 fb^{-1}

Searches for non-standard Higgs bosons

M. Carena, S. Heinemeyer, G.Weiglein,C.W'05, to appear in EJPC

- Searches at the Tevatron and the LHC are induced by production channels associated with the large bottom Yukawa coupling.

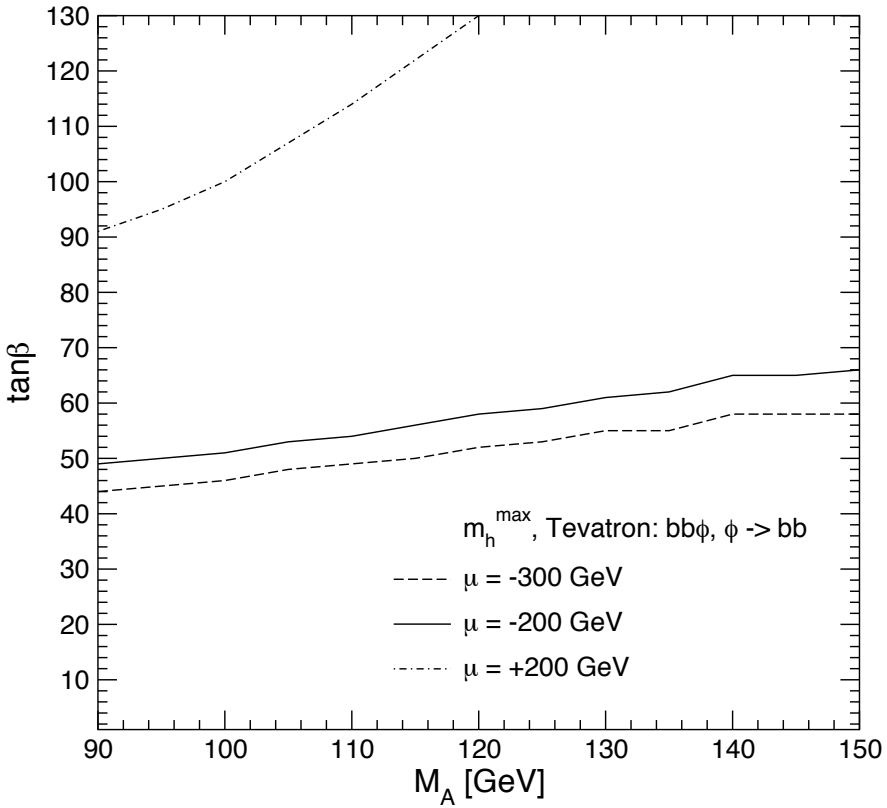
$$\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

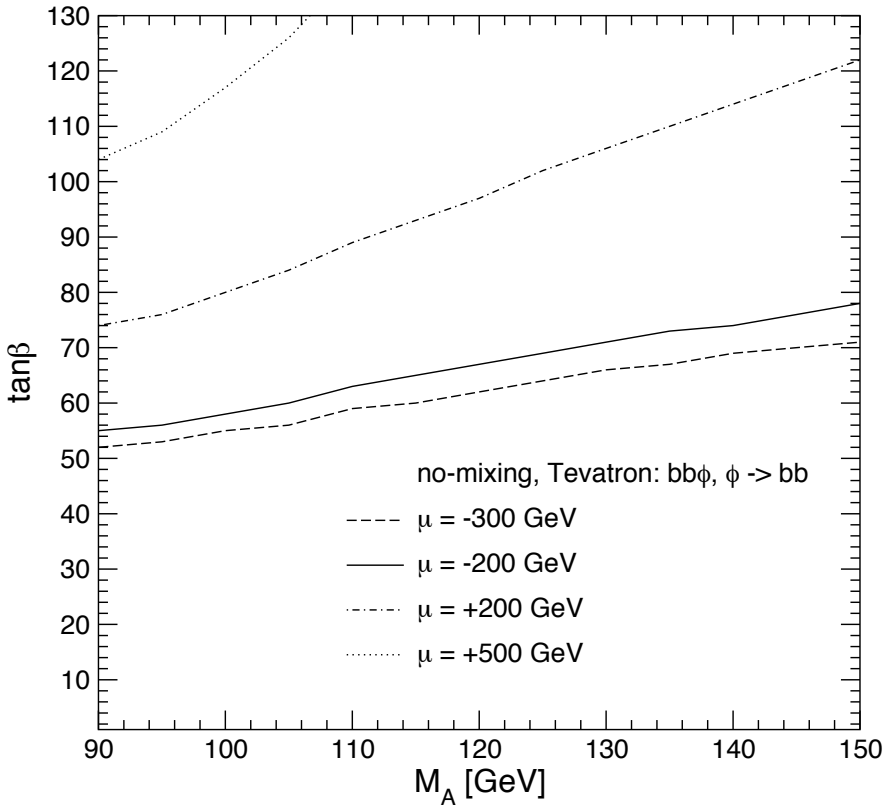
$$\sigma(b\bar{b}, gg \to A) \times BR(A \to \tau\tau) \simeq \sigma(b\bar{b}, gg \to A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2+9}$$

- Since, depending on the parameters, $\Delta_b \simeq \pm\mathcal{O}(1)$ there may be a strong deependence on the parameters in the bb search channel, which is strongly reduced in the tau tau mode.
- The tau mode provides a more stable definition of the bound on $\tan\beta$ as well as of the future reach of the LHC.

Searches at the Tevatron in the bb mode. Current limits from D0

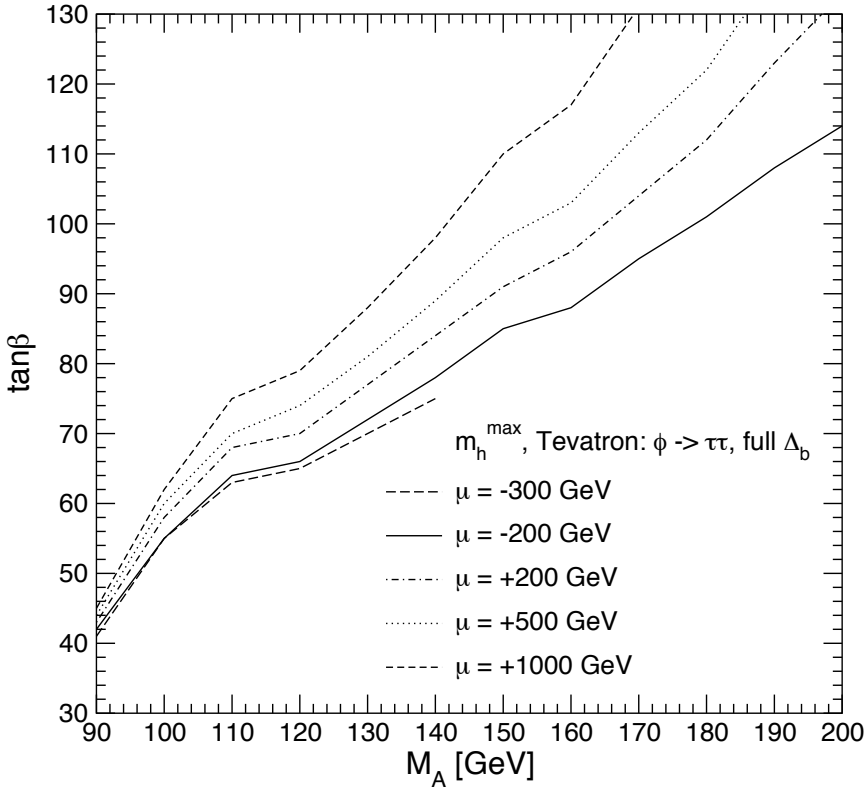
M. Carena, S. Heinemeyer, G.Weiglein,C.W'05, to appear in EJPC

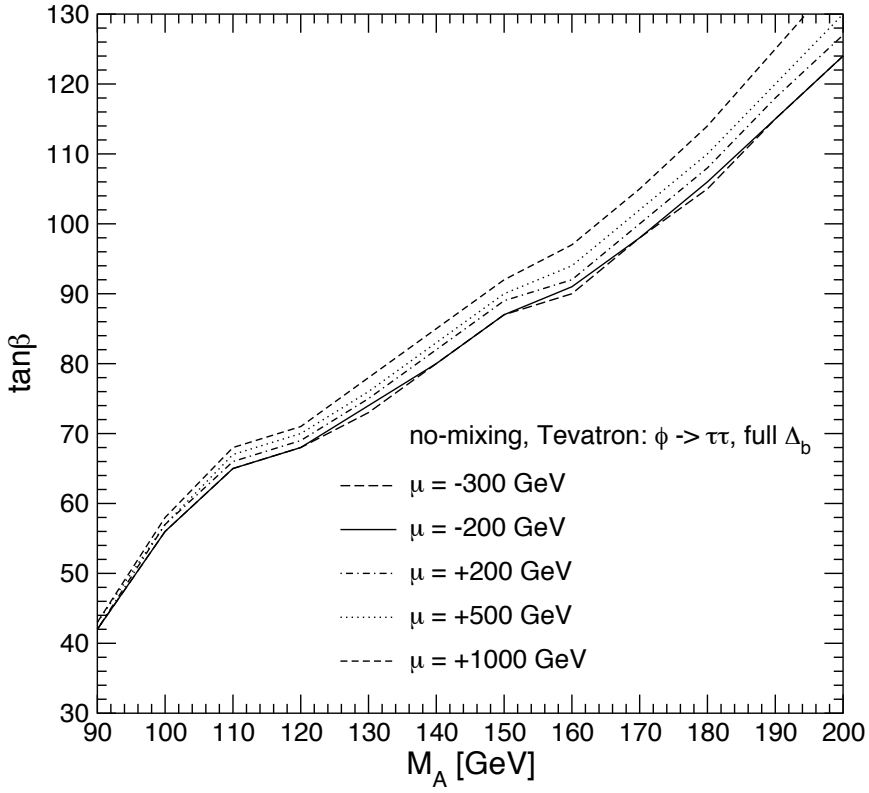




Searches at the Tevatron in the tau tau mode

M. Carena, S. Heinemeyer, G.Weiglein,C.W'05, to appear in EJPC

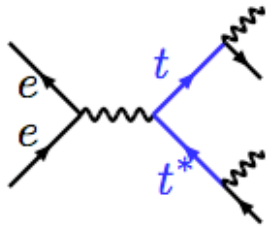




Measuring the W-t-b coupling at the ILC (P. Batra, T. Tait)

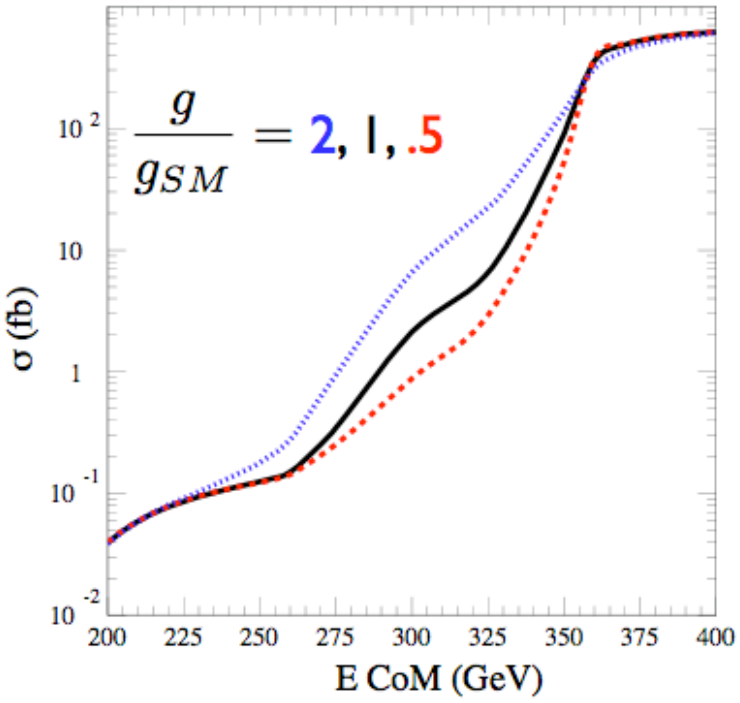
Above threshold, $t\bar{t}$ production is insensitive to the W-t-b coupling

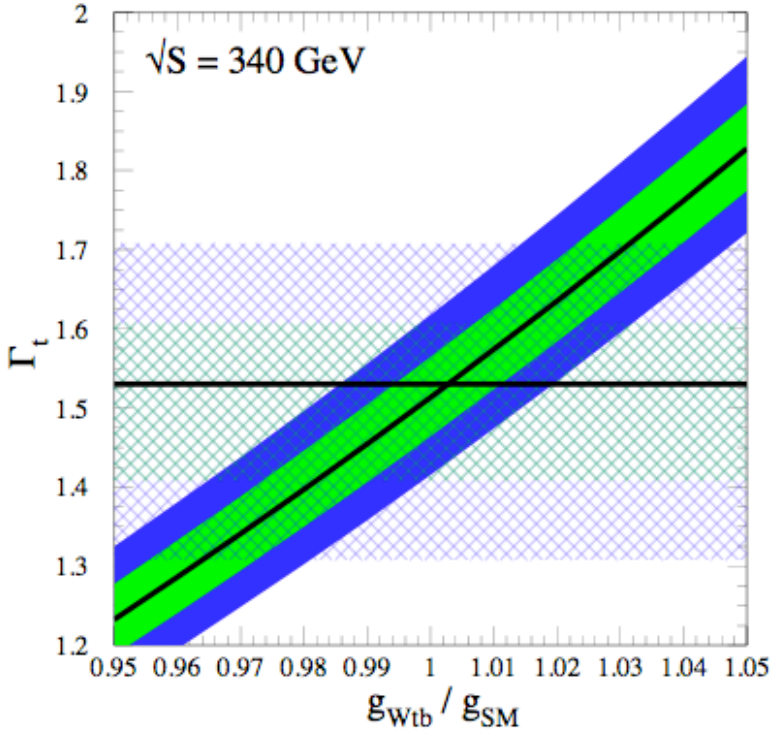
An extended top sector can shift this coupling wtihout opening up new decay channels!
(4th generation, Little Higgs models, Top seesaw, ...)



Crucial test of the Standard Model Electroweak interaction $g\ \bar{t_L}\ W b_L$

Can go to virtual $t\bar{t}$ production, below threshold, to gain sensitivity.



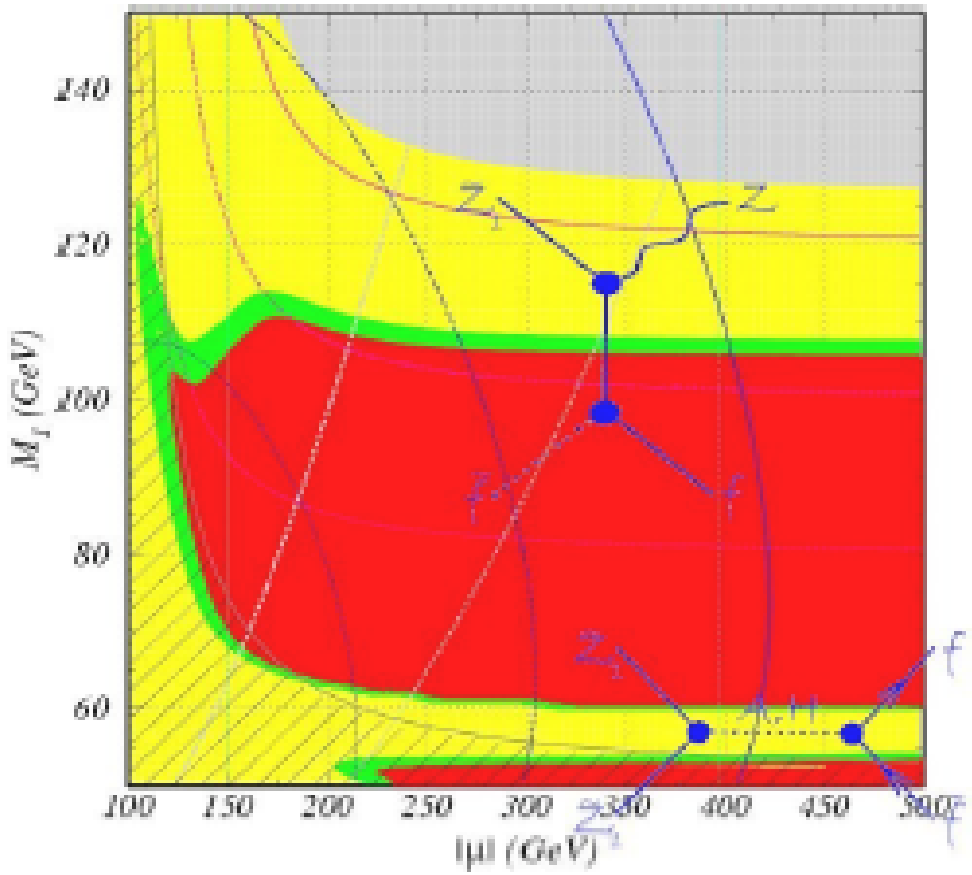


A few percent measurement of the W-t-b coupling is possible!

Cosmology and Astroparticle Physics

Supersymmetric Origin of Matter

A scalar top quark lighter than the top and a light Higgs, with mass smaller than 120 GeV, enable the realization of electroweak baryogenesis



Balazs, Carena, Menon, Morrissey, Wagner, Phys. Rev. D 71, 075002 (2005)

Baryon asymmetry and dark matter can be simultaneously generated in the MSSM – green → Ω_{CDM} consistent with WMAP

$M_2 \sim 2\, M_1 \rightarrow \tilde{Z}_1 \sim$ bino → high Ω_{CDM}

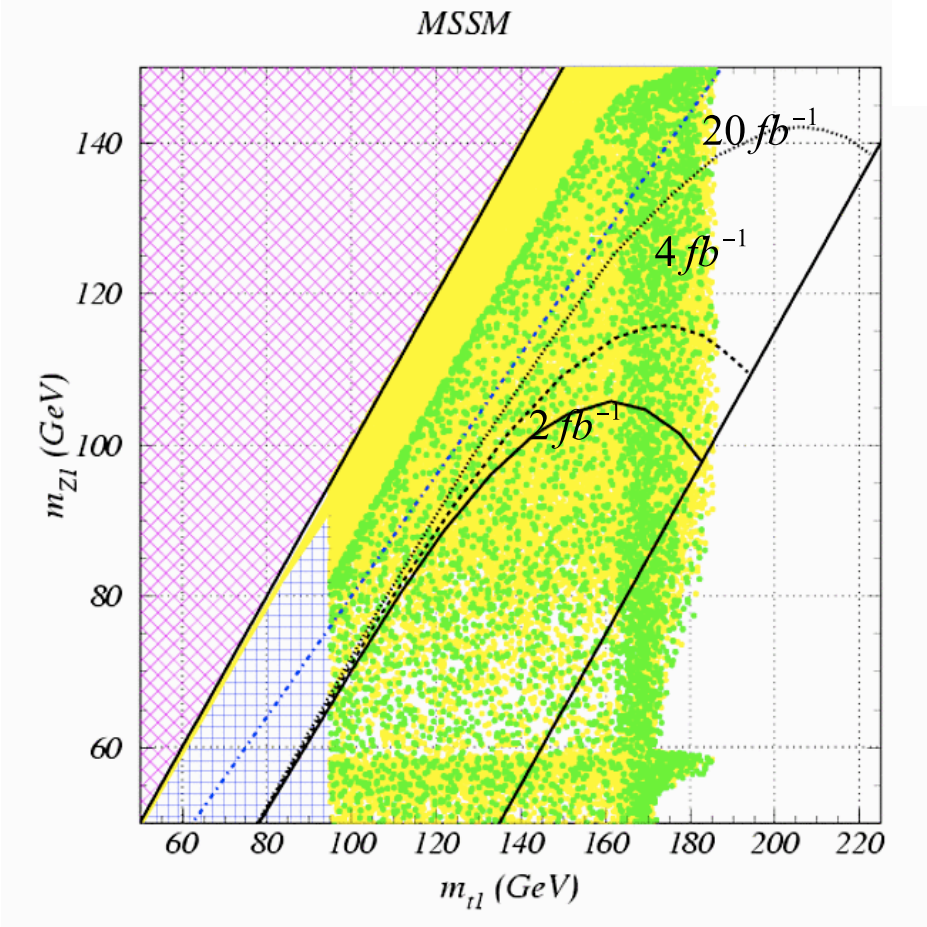
$\tilde{t}_1 - \tilde{Z}_1$ coannihilation lowers Ω_{CDM} where $m_{\tilde{t}_1} \sim m_{\tilde{Z}_1}$ ↔ light stop

Annihilation via h^0, A^0 resonances lowers Ω_{CDM} for $2\, m_{\tilde{Z}_1} \sim m_{h^0(A^0)}$

Tevatron stop searches and dark matter constraints

M. Carena, C. Balazs and C. Wagner

Phys.Rev.D70:015007,2004



Balazs, Carena, Menon, Morrissey, Wagner, Phys. Rev. D 71, 075002 (2005)

Green: Relic density consistent with WMAP measurements.

Searches for light stops difficult in stop-neutralino coannihilarion region.

LHC will have equal difficulties. Searches become easier at a Linear Collider !

Non-Perturbative Analyses

Y Brihaye, C Hill & C Zachos, Phys Rev D70 (2004) 111502;
C Hill and C Zachos, Phys Rev D71 (2005) 046002.

GAUGED SKYRMIONS AND WZW INTERACTIONS IN DIMENSIONAL DECONSTRUCTION

Dimensional deconstruction is the intricate systematic accounting of correspondences of higher-dimensional gauge theories into $D = 4$ matter-coupled gauge theories, including current models for electroweak interactions.

• Unexpected correspondence rules discovered in examining the **consistency of covariant derivatives** (Bianchi Identities) involving the lowest K-K modes with the anomaly and topological structure of such theories.

⇝ Insight into a long-standing enigma: the connection between Chern-Simons topological interactions in odd-dimensional gauge theories and Wess-Zumino-Witten terms in even dimensional chiral models—terms required in effective QCD, but so far inaccessible to deconstruction methods.

Summary

- Theory Group is very active on a broad range of subjects, including collider physics, QCD, Higgs physics, BSM physics, mathematical physics and lattice gauge theories.
- The Group has strongly profited from its interactions with the University of Chicago.
- These interactions served to create joint faculty, postdoctoral and student positions which have greatly enhanced the productivity of both the University and Laboratory HEP groups.
- A similar collaboration with Northwestern University would be strongly welcomed.